CHAPTER 18

ELECTRONIC GROUNDING

The evaluation and preparation of a site, in reference to the electronic groundings, is the responsibility of the Naval Facilities Engineering Command (NAVFAC) who will determine and install the required grounding system. Naval Electronics System Command personnel are responsible only for the grounding of the electronic equipment to the site's overall grounding system.

It is strongly recommended that personnel concerned with grounding of electronic equipment consult the following publications for more precise information.

- o NAVELEX 0101, 102, Naval Communication Station Design.
- o NAVELEX 0101, 104, HF Radio Antenna Systems.
- o NAVELEX 0101, 106, Electromagnetic Compatibility and Electromagnetic Radiation Hazards.
- o NAVELEX INST 011120.1, Shore Electronics Engineering Installation.
- o NAVFAC DM-23, Communications, Navigational Aids, and Airfield Lighting.
- o MIL-STD, Military Communication System, Technical Standards.
- o National Electric Code Handbook (NECH)

18.1 RECEIVER BUILDING GROUND

Receiver building and equipment grounding has been investigated by the Naval Electronic Systems Test and Evaluation Facility (NESTEF), St. Inigoes, Maryland. The conclusions were:

- o The controlling factor affecting RF signal reception is external noise (spheric, cosmic, and man-made) entering the receiver via the antenna.
- o A very low resistance earth-ground connection is expensive to install, hard to maintain and adds nothing to the operational efficiency of a modern receiver.
- o Bonding and grounding of structural metal which is no longer than 24 inches is of value only when signal reradiation is deemed possible.

The recommendations of this report are the grounding criteria for the receiver building, provided Red and Black processing (exclusive of orderwire traffic) will not be

required. The signal grounding system for Red and Black circuits must be in accordance with the latest issue of NAVELEX INST 011120.1. (A discussion of Red and Black signal grounding is also included in NAVELEX 0101,102.)

The following criteria govern the grounding system of a receiver building the location of which presumed to be as recommended, provided that the building is not collocated with a transmitter site.

- One ground connection point will be used for both electrical and communications systems.

- Resistance of the ground system to solid earth must comply with the provisions of article 250-84 of the National Electrical Code Handbook.

- Bonding and grounding of structural metal which is longer than 24 inches (not normally required) is to be treated on an individual-case basis.

18.1.1 Receiver Building Earth Ground Connection

A good earth ground connection can be established by selecting a grounding electrode recommended in articles 250-81, 82, and 83 of the NECH. A general discussion of installed electrodes and recommended test methods is included in NAVELEX 0101,102 and 0101,106.

18.1.2 Receiver Building Ground Distribution Systems

The receiver building ground distribution system emanates from a common ground bus that is connected to the selected earth ground connection point. All ground systems must terminate on this bus.

18.1.3 Ground Bus to Earth Ground Point Interconnection

The criteria for connection between the ground bus and ground point for the receiver building are:

a. Connection between ground bus and earth ground point must be made with a conductor that runs either directly to the earth ground point or to the main electrical service entry point ground lead which is in turn run to the earth ground point.

b. The size of the conductor connecting the bus and earth ground point must not be less than that specified by article 250-94 of the NECH. Number AWG6 copper wire, or its equivalent in amp capacity, is sufficient to connect to any electrode serving as the ground point.

c. The conductor connecting the ground bus to the earth ground connection point must be attached by a suitable ground clamp, terminal screw, or pressure connection.

18.1.4 Ground Bus to Equipment Distribution

The criteria for ground distribution between equipment and the ground bus for the receiver building are:

a. All electronic equipments and component parts of an electronic system must be provided with a separate grounding conductor to connect the electronic equipment to the ground connection point. This conductor is normally the third wire (green AC protective ground) of the power feeder.

b. Grounding conductors must be routed with circuit power conductors from electric distribution panelboards to the cabinet or rack that houses electronic equipment.

c. Grounding conductors must have a green covering with or without yellow stripes.

d. The grounding conductor must be the same size as the power conductors with which it is routed.

18.1.5 Ground Conductor Termination

The criteria for terminating the ground conductor to electronic equipments in the receiver building are:

a. The grounding conductor must be terminated directly to the ground terminal (if provided) on the electronic equipment. (This can be accomplished easily when a single power feeder supplies power to an individual equipment.)

b. If grounding terminals are not provided on equipments, grounding can be accomplished by bonding the ground wire to the equipment enclosure.

c. When several equipments are mounted in a cabinet or rack and power is supplied by a single power feeder, a ground bus should be installed to facilitate grounding. The following restrictions and procedures apply:

(1) The bus should be of highly conductive metal. (Copper is preferred.)

(2) The ground conductor should be bonded to the bus.

(3) Bonding between the ground bus and equipment must be accomplished using approved bonding techniques.

(4) The third (green) wire of the AC plug and power cord is retained, but does not by itself meet the grounding requirement.

18.1.6 Ground System Testing

The connections of the grounding distribution system should show a resistance no greater than 0.5 ohm between:

a. Equipment ground (terminal or enclosure) and grounding electrode (ground wire leading to equipment).

b. Equipment ground (terminal or enclosure) and ground bus of the AC power source (grounded neutral of the power feeder).

c. Equipment ground (terminal or enclosure) and cabinet or rack in which it is installed.

d. Equipment ground (terminal or enclosure) and all other grounding systems within the building.

18.2 COMMUNICATION CENTER

The communications center building does not require special grounding or bonding for its structural members. One grounding system is required for personnel and equipment protection, and a second grounding system is required to ground the signal circuits. The personnel and equipment protective ground system is the AC (green-wire) protective ground distribution (see NAVELEX 0101,102). The earth ground connection point for the AC ground distribution system must comply with article 150-84 of the NECH.

The criteria for the signal ground system are contained in NAVELEX INST 011120.1. The following general requirements must be met:

a. The signal ground system may have its own ground connection point. NAVELEX INST 011120.1 specifies the type of connection to be used for both large and small systems.

b. Separate ground distribution systems are required for Red and Black signal grounds. NAVELEX INST 011120.1 specifies when and where these two systems are to be interconnected.

18.3 TRANSMITTER BUILDING GROUND

NAVFAC DM-23-"Communications, Navigational Aids, and Airfield Lighting," should be used as the source of criteria for bonding and grounding of transmitter buildings.

18.4 ANTENNA GROUND PLANE

A ground plane is required for any ground-mounted antenna if the antenna is fed in a manner that makes the earth the return path for current flow. An arrangement of wires comprising a ground plane improves antenna radiation efficiency and provides an

improved low-loss path for the return current. Conical monopoles, discones, inverted cones, sleeves, and some vertical LPS'a are typical of the antennas requiring ground planes. Ground planes can be considered in three basic categories: radial grounds, ground mats and counterpoises.

18.4.1 Radial Ground Plane

A radial ground plane, generally the most effective grounding configuration for vertical antennas, is constructed of radial wires originating from a point at the antenna base. Ground radial kits are supplied as standard items with some vertical antennas (conical monopoles, inverted cones, and vertical monopole LPS's). General specifications for ground radial materials and installation are:

a. Radials should be at least one-quarter wavelength long at the lowest design frequency of the antenna. The gauge of the radial wires need only be sufficient to withstand the mechanical stresses of installation. (Usually 8 or 10 AWG annealed copper-clad steel wire is adequate.) To increase the ground plane, the lengths of the radials should be increased rather than the wire cross-sectional area.

b. Radials are most effective when installed on the earth's surface. However, radials are normally buried to ensure physical protection. The depth of burial varies with frequency, and should conform to the following rules:

(1) Frequency $\leq$ 9 MHz - burial depth $\leq$ 6 inches.

(2) Frequency > 9 MHz - burial depth $\leq$ 3 inches.

c. Where terrain or boundary conditions prohibit the desired radial length, connection of each radial to a ground rod is recommended, provided that the rods can be driven at least 3 feet into the ground. (Ideally, the rods should be set 10 feet into the earth's surface at most antenna locations.)

Peripheral bonding of the radials to a closed loop of wire that surrounds the ground plane is recommended, whether or not ground rods are used. Silver soldering, brazing, and exothermic welding are acceptable bonding methods. When ground rods are not used, the radials should be staked as necessary to ensure physical stability.

d. On installations where radials of adjacent antennas cross each other, interference may be generated by non-linear junctions formed where the radials overlap. The following alternatives may be followed as best suited to the particular application:

(1) Bond radials at each crossing point.

(2) Use insulated wire for the radials, or insulate the wires at each crossing point.

(3) Substitute a copper-mesh ground mat for the radial ground plane. (The dimensions of the mat should be determined on an individual-case basis.)

(4) Bury the radials of the affected antennas at different depths at the crossing points, keeping the higher-frequency antenna's radials nearest the surface.

18.4.2 Ground Mat

When high antenna base-currents are present, a copper-mesh ground mat is required at the antenna base to further insure against ground-system power loss. A typical mat is 12 feet square and is fabricated from expanded copper or from copper wires bonded together to form a grid. Installation practices are the same as those specified for radial systems.

a. If a mat is used in conjunction with a system of radials, ensure that each radial is bonded to the mat.

b. If local surface characteristics prohibit mat burial, lay the mat on the surface and stake it at frequent intervals to prevent shifting.

c. The primary consideration for the gauge of wire or thickness of expanded copper to be used in the mat depends on the anticipated mechanical stresses.

18.4.3 Counterpoise

A system of conductors elevated above and insulated from the earth constitutes an antenna counterpoise which forms a large capacitance with ground. This counterpoise simulated a ground plane to stabilize antenna impedance. The following considerations should be observed for effective application of a counterpoise:

a. It must be placed directly under the antenna.

b. It must be scaled in size according to operating frequency. The size must be adequate to provide capacitance of a value that will have low reactance at the operating frequencies, thus minimizing any potential difference between the counterpoise and ground.

18.5 INSTALLATION OF GROUNDING SYSTEM

Methods and practices for establishing and testing grounds are included in NAVELEX 0101,106 and NAVELEX 0101,102.

18.5.1 Ground Rods

Driven electrodes (ground rods) are used for the earth ground connection where bedrock is beyond a depth of 10 feet. Since these electrodes are subject to the corrosive action of the earth, they should be made of copper-clad steel. These electrodes, available commercially in various lengths and diameters, can be joined together to extend their length. Generally, the electrode depth determines the resistance of the earth ground connection. Rods should be driven deep enough to reach the permanent moisture level of the earth whenever possible. Failure to reach this level may result not

only in high resistance, but may also cause large resistance-variations during seasonal weather fluctuations. In installing ground rods, the following criteria should be followed:

a. Check site of proposed ground rod(s) against site plans, or with a metal locator to select a location clear of buried cables or pipes.

b. Short rods can be driven manually using a four-pound sledge hammer. Use either manually-operated or power-driven devices for rods eight feet or longer in length. Be careful not to bend the rod.

c. Attach the ground lead to the ground rod with an approved clamp which will provide permanent, low-resistance, metal-to-metal connections. One method of making a permanent connection is to weld them together using a small charge of thermit. A mold is formed around the lead and rod connection, the thermit is fired which melts and fuses the ground lead and rod together.

18.5.2 Ground Mats

Ground mats in the form of a grid system consisting of copper wires or cables buried about 6 inches in the ground are sometimes used at shore facilities. The mat requires a large surface area, and installation must be made at the early stages of site construction and the mat then covered with fill. Applicable site plans and specifications must be carefully followed for precise installation instructions. The purpose of the grid is to provide equipotential areas throughout the entire facility, avoiding any gaps where differences in potential would be hazardous to life or property.

The mat may be made up by two different methods:

a. When the spacing of individual conductors is greater than 24 inches (it may be as great as 10 feet) the conductors may be run separately, the cross-connections bonded at each crossover, and tied into the facility ground.

b. When conductor-spacing is less than 24 inches, the most economical method is to use presoldered rolls of wire. These rolls are available in widths up to 12 feet, and in lengths up to the limiting weight of 600 pounds. The shipping weight of the most common mesh size (24 by 24 inches, No. 6 AWG wire) is 550 pounds for a 12-by 600-foot roll. Individual rolls should overlap each other by about three inches and be bonded together. The complete mat is tied in with grounding rods.

18.5.3 Buried Plates

Grounding plates, strips, and sheets of copper or Everdur are used when the physical configuration of the site prohibits use of more conventional grounding systems. The resistance of a plate ground is dependent on the area of the plate. A plate of about 20 square feet of surface area (top and bottom) is the most efficient to use for plate size and maximum decrease in resistance. Increasing the plate size beyond 20 square feet does not result in an appreciable decrease in resistance.

Connection to the plate is made by means of a strap not less than 12 inches wide x 0.032 inch thick which is brazed to the plate. To minimize RF losses, the plate should be as close as possible to the transmitter or the antenna.

Strip electrodes are superior to plates or sheets. The larger distribution area forms a high electrostatic capacity to ground and thus a low RF resistance. A network of two-inch wide strips about three feet in depth, has proved effective. Strips 25 feet long spaced at ten-foot intervals make an efficient grounding system. The number of strips to use should be based on soil resistivity and equipment criteria.

18.5.4 Radials

Radials complement antenna systems and must be cut to proper length. The wires extend radially from a central grounding point (wagon wheel design) to an outer ring where each wire is terminated in a ground rod. The wires should be buried to a depth that affords protection from surface traffic, but should not be buried too deeply. Too-deep burial may result in dielectric losses for higher frequencies at the earth's surface.

18.5.5 Structural Groundings

The large mass and large number of parallel paths to earth of a steel-building structure can provide excellent grounding. Wide, low-inductance straps should be brazed to the frame and to each individual floor's cable trays, ducting, and cellular metallic flooring (if used). Strap material should have a width-to-length ratio of 1:5 or less.

18.5.6 Distribution

The primary objective is to provide a connection that has as low a resistance as practicable for interfering signals, power-leakage currents, and RF energy. A conductor or system of conductors that has a large surface area will satisfy the above requirements. Connections made between the distribution bus and the individual ground jumpter, and between the jumper and equipment, shall have a surface contact area which does not degrade system operation. The connection shall be brazed or silver-soldered to bus bars for permanent connections. The surfaces of equipment cabinets and racks must be cleaned down to bare metal at the point where the grounding strap will connect. Care must be taken to remove anodized finishes from aluminum or magnesium; these finishes, although metallic in appearance, have a high ohmic resistance.

Solid strap material is always preferrable. Braid or stranded straps are not authorized in Naval Shore Facilities.

18.6 IMPROVING GROUNDING EFFICIENCY

When low resistance grounds are difficult to establish due to the characteristics of the earth and weather conditions, a number of methods may be used to lower the resistance, the most effective of which are described below. For additional information in reference to Grounding Efficiency, please refer to NAVELEX 0101,106.

18.6.1 Deep-Driven Electrodes

The resistance contributed by the soil is the principal component of ground resistance. Increasing electrode depth results in a decrease in ground resistance which is almost equivalent to that of connecting an increasing number of electrodes in parallel. If the rod is sectional, additional sections may be added and the rod driven to the required depth. If not, a sectional rod of the required length must be driven adjacent to the old rod and the combination tied in parallel. The major limiting factor to applying this method is the presence of rock at greater depths.

18.6.2 Multiple Electrodes

To obtain the specified ground resistance, multiple electrodes connected in parallel may be more practical than increasing grounding rod depth. Since 90 percent of the total resistance is located within 6 to 10 feet of the electrode, the placement of two or more electrodes within overlapping spheres will not proportionally decrease ground resistance.

18.6.3 Chemical Treatment

Multiple-driven electrodes will not always provide adequate low resistance to earth. In such instances, it is usually possible to reduce the resistivity of the soil immediately surrounding the electrode by treating the soil with a substance which, when in solution, is highly conductive. There are several substances; the better known, in the order of preference, are:

- Magnesium sulphate ($MgSO_4$) - epsom salts.
- Copper sulphate ($CuSO_4$) - blue vitriol.
- Calcium chloride ($CaCI_2$).
- Sodium chloride (NaC_1) - common salt.
- Potassium nitrate (KNO_3) - saltpeter.

Preference is given to use of magnesium sulphate, as it combines low cost with high electrical conductivity and low corrosive effect on a ground electrode or plate. All electrodes used in the soil-treatment method should be of copper clad steel.

Large reductions in ground contact resistance of individual electrodes may be expected after treatment of the earth. The initial effectiveness of treatment is greatest where the soil is somewhat porous because the solution permeates a considerable volume of earth, and ground contact thereby increases the effectiveness of the electrode. When soil of compact texture is encountered, the treatment is not as effective at first because the solution tends to remain in its original location for a longer period of time. Treatment limits the seasonal variation of resistance and lowers the freezing point of the surrounding soil. Treatment using a magnesium sulphate and water solution is as follows:

a. An 8-inch tile pipe about four feet long is buried in the ground about four inches from the ground electrode, and filled to within one foot of ground-level with a magnesium sulphate and water solution. The pipe should have a wooden cover with holes, and be located at ground level.

b. Forty to 90 pounds of chemical will initially be required to retain effectiveness for two or three years. Each replenishment of chemical will extend effectiveness for a longer period, so that re-treatments are needed less and less frequently.

Common salt and saltpeter should be used only if none of the other chemicals listed above are available, as these agents are very corrosive.

18.7 BONDING

Bonding is the process of physically connecting two metallic surfaces to provide a low impedance path for electromagnetic currents. Bonding permits currents generated by the coupling action between units to flow readily to ground rather than allow a difference in potential to build up until the accumulated energy is sufficient to break down the resistance of the gap and arc across. Arcing is a serious source of RF interference; bonding is an effective means of interference suppression.

18.7.1 Methods of Bonding

a. Direct Bonds. Direct bonds consist of permanent or semipermanent, metal-to-metal contact joints between mating parts. Permanent joints may be made by welding, brazing, or sweating, and are best from the viewpoint of mechanical strength and providing low-impedance paths. Semipermanent joints of machined metallic surfaces rigidly held together by bolts, lockwashers, pins, clamps, or other devices, provide excellent direct bonds that insure continuous electrical contact if the contact areas are clean and all protective coatings have been removed before assembly.

b. Indirect Bonds. When a direct bond is not practical, an indirect bond (a jumper or strap made of tinned copper braid) may be used to provide the necessary electrical conductivity between units not in firm mechanical contact. Tooth-type lock washers with bolt and nut are used to ensure positive metal-to-metal contact. Indirect bonds are used with shock-mounted equipment and for structural parts of a vehicle and power units which cannot be bonded together for mechanical reasons. When a jumper is used, inductance is introduced into the circuit which may be a cause of trouble at radio frequencies. To minimize the amount of inductance introduced, the length-to-width ratio of the jumper should not exceed 5 to 1.

18.7.2 Bonding Requirements

a. All metal components located within the field of a device which produces radio noise or conducts interference currents must be bonded. Metal parts which are normally fastened together should be bonded together. All movable metal parts located within a field, or subjected to conducted interference, should be used whenever shielding is penetrated by a metal part, and whenever filters and capacitors require good

groundings. Whenever other suppression methods are used, bonding should also be considered, since lack of (or poor) bonding can nullify the effects of all other suppression methods.

b. Bonding techniques must be used in the application of other suppression measures themselves. The mountings of filters and capacitors, the joints of shields, and even the terminals of bonding jumpers must be bonded.

c. All electrical conduits, flexible and rigid, should be terminated with a good bond at each end. Whenever possible, bond these conduits to a ground at about two-foot intervals with bonding jumpers.

d. Bonding applies to shields and shielding conduits as well. Flange fittings, shield can covers, and joints should all be bonded, applying the same principles used in other applications.

18.7.3 Bonding Installation Practices and Precautions

a. Always attach bonds to an electrically clean surface. Remove all paint, corrosion, and oxide films, and clean the surface down to the bare metal. An ordinary clean surface is insufficient since coatings invisible to the naked eye and resistance to solvents may exist.

b. The outer surface of long spans of braid-shielded conduit constitutes a possible high-impedance path for interfering currents. To offset this possibility, such cables should be bonded to ground at both ends and at intermediate points.

c. The ill effects of inductance may be offset by keeping the bond strap as short as possible, and by using a bonding jumper wider than it is thick.

d. Use tooth-type lockwashers, preferably internally and externally toothed, in all applications where screws or bolts are used, and tighten them so that the teeth bite into the metal surface.

e. When attaching suppression components, such as filter capacitors, to equipment, treat the joints made as bonds. Be sure to have clean, dry mating surfaces.

f. Treat the terminals or other means of attachment at both ends of a jumper as bonds. A jumper is only a substitute at best, and, when improperly attached, can be a source of interference.

g. Ensure that the mating surfaces of direct bonds are dry before bonding, and that the joint is held together under high pressure to prevent moisture from creeping into the joint and causing corrosion.

h. Treat all joints in shielding as bonds.

i. Washer nuts, bolts, or screws that have been anodized or similarly treated to resist corrosion should not be used since they increase the impedance of the bond. Corrosion and fungi-proofing material have to be removed from mating surfaces of all bonds, because they tend to insulate.